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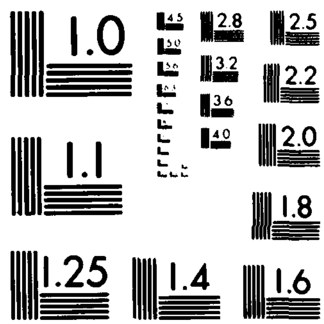

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RESIDUAL STRESS MEASUREMENTS ON ALUMINUM-GRAPHITE COMPOSITES USING X-RAY DIFFRACTION TECHNIQUES

by

S. Tsai, D. Mahulikar, H. L. Marcus, I. C. Noyan and J. B. Cohen

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"RESIDUAL STRESS MEASUREMENTS ON ALUMINUM-GRAPHITE COMPOSITES USING X-RAY DIFFRACTION TECHNIQUES"

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INTRODUCTION

Metal Matrix Composites (MMCs) have generated considerable interest in the materials field, because of their potential applications in dynamic structures. A MMC with its excellent mechanical as well as physical properties carries a distinct advantage over other composite systems, particularly at high temperatures. At the same time a MMC system is characterized by heterogeneity, anisotropy and interfaces which affect those properties considerably. Interfaces have been known to influence the properties of MMCs significantly and their importance has been discussed extensively[1]. However, the interface chemistry and its exact role in alteration of various properties is not well-known yet. One of the important things needed for better understanding of the interface is its stress state. Thermal and mechanical treatments involved in the fabrication of composite materials, give rise to triaxial

residual stresses[2]. Speculations are that these stresses, originating from the differing thermal coefficients of the reinforcement and the matrix, play an important part in the transverse properties of the MMCs.

A simple calculation using a planar model[3] shows that stresses well above the yield strength of aluminum exist at the interface of the aluminum-matrix-graphite fiber composite system. This occurs because the graphite fibers are introduced into molten aluminum and during the subsequent cooling, aluminum contracts much more than the graphite in the fiber direction. Plastic flow is expected to occur because of the high values of thermally induced stresses in that direction. Assuming no debonding, a stress gradient is expected in the Al matrix, with above-yield tensile stress at the interface. A schematic of the expected stress distribution in the longitudinal direction is given in Fig. 1. The dotted line represents average value of stress in the aluminum matrix. All of the matrix is expected to be in a state of tensile stress minimized at a point between fibers.

While there is a significant difference in thermal expansion coefficients of Al and graphite in the longitudinal direction, this difference is negligible in the transverse direction due to the anisotropy of graphite fiber. Therefore, the residual stresses in the transverse direction are mechanical in origin due to the development of the longitudinal stress and are not expected to be as high as those in the longitudinal direction.

Cryogenic cooling induces additional plastic flow in the matrix establishing a new elastic condition at the cryogenic temperature. Heating the composite back to room temperature will then relieve much of the residual stresses.

For experimental verification of the above mentioned observations, residual stress measurements are essential. This paper discusses a method of residual stress measurements for composite systems and presents several results. The data obtained is then interpreted with reference to the models described earlier and relative to the finite interface between the aluminum matrix and graphite fiber.

EXPERIMENTAL PROCEDURES

The residual stress measurements were made on three different transverse strength aluminum-graphite composite systems. The nominal properties and the fiber and matrix components of the systems are given in Table 1. The measurements were also made on samples quenched to liquid N_2 temperatures and then tested at room temperature.

The X-ray diffraction technique was used for the stress measurement. The measurements were made on a computer controlled Picker powder diffractometer using parafocussing geometry. This particular technique involved use of the $\sin^2\Psi$ method described elsewhere[4]. Six Ψ angle tilts taken in equal increments were employed. The surface components of the stress were obtained by a computer for a least square straight

line fit to the lattice strain as a function of $\sin^2\Psi$. (Peak positions were determined with an 11 point parabolic fit.) Only those data with a correlation factor of 0.95 and above were considered sufficiently accurate. In order to counteract grain size effect 2θ oscillations of 2 degrees were employed. A cobalt X-ray source of 0.15 cm^2 area was employed; 90 percent of the intensity came from a depth of 5.4×10^{-3} cm. Due to the relatively large divergent beam, the stress measurement obtained was a volume average over the matrix similar to one represented by the dotted line in Fig. 1. For such a volume average, the penetration depth of X-rays becomes an important parameter. Since it is the stress in the vicinity of the interface that is of interest here, it is absolutely essential to expose the interface of the specimen to the X-rays. In other words, the penetration depth should be such that the X-rays average over the region which includes interface.

Mechanical polishing was not used since it could introduce residual stresses. By electropolishing, enough surface could be removed so as to expose the interface area, and to get rid of the surface layer that may have been stressed by mechanical working. For G 3437 and G 3394 the sample surfaces were polished just enough to expose portions of interfaces. With G 3675 only light electrolytic polishing was done. This resulted in a thin surface layer of aluminum above the fibers having thickness greater than the penetration depth of the X-rays used. Thus during volume averaging only the aluminum matrix containing no

fibers would be covered and not the interfacial area. Specimens used were plates with a thickness of approximately 0.4 cm, and 1.9 to 2.5 cm width and length. Residual stress measurements were made in both the longitudinal and transverse direction as indicated in Figure 2.

RESULTS AND DISCUSSION

The residual stresses measured with the 420 diffraction peak of aluminum are listed in Table 2. The table also lists the correlation factors for the least-squares straight line fit for the lattice strain vs $\sin^2\Psi$.

It may be noted that the longitudinal fiber stress values for G 3437 and G 3394 are comparable to the yield strength of the 201 aluminum matrix, indicating that the longitudinal interfacial stress is even higher than this average value which was predicted by the simplistic planar model. This also seems to support the presence of plastic flow.

However, in the transverse direction, significant stresses are noted in the G 3437 and G 3394 specimens. In the absence of a significant difference in thermal coefficients of expansion of the matrix and fiber in that direction, one expects the thermal stresses to be much lower than those in the longitudinal direction. The yielding of the aluminum probably gives rise to the observed large residual stresses.

For the G 3675 composite, which was electropolished only slightly with almost no interfacial region exposed, very low

stresses were observed. This was because the X-rays did not include appreciable amounts of the interfacial region below the surface layer of aluminum, and hence no interfacial stress contribution was recorded.

An interesting observation was, that while the transverse fracture strengths of the composites varied (Table 1), the recorded residual stresses varied only slightly. This indicated that the residual stresses may not be affecting transverse strengths to any appreciable extent.

The model described in Fig. 1 did not consider a finite thickness interface. It has been observed[5,6] that an oxide, carbide, or titanium diboride is usually present at the fiber matrix interface in Al-graphite systems. Since the mismatch between the thermal coefficients of the compounds and the aluminum matrix is lower than that of the fiber and the aluminum in the longitudinal direction, the longitudinal residual stresses at the interfaces can be expected to be lower than when an aluminum graphite interface exists. It is the interfacial chemistry which is responsible for a particular mismatch in thermal coefficients.

When the G 3437 composites were quenched in liquid nitrogen and annealed at room temperature, approximately 30% reduction in residual stress was observed. This is less of a reduction than is calculated from the differences in coefficient of thermal expansion. Additional work hardening at the interface occurring during cooling may explain this difference.

Additional research is being conducted to study the residual stress effects in Al-graphite and other metal matrix composites. Higher energy X-rays will be used to increase the penetration depth with a respective rise in averaged volume. Interface chemistry and its influence on transverse properties is under investigation.

CONCLUSIONS

1. X-ray diffraction is an effective procedure for measurement of residual stresses in metal matrix composite systems.
2. Large longitudinal residual stresses were observed in Al-graphite composites.
3. Transverse residual stresses were observed in spite of the limited mismatch in the thermal expansion coefficient in that direction.
4. No large difference in the residual stresses for two different transverse strength Al-graphite systems was measured.
5. Quenching a composite in liquid N_2 and annealing it at room temperature reduced the stresses by approximately 30%.

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REFERENCES

1. COMPOSITE MATERIALS, v.1 "Interfaces in Metal Matrix Composites" Ed. A.G. Metcalfe, Academic Press, 1974.

2. Ebert, L.J. and P. Kennard Wright, "Mechanical Aspects of the Interface" in Composite Materials, v.1, ed. A.G. Metcalfe, Academic Press, 1974, p. 53.

3. Hoffman, C.A., (1970) Effects of thermal loading on composites with constituents of differing thermal expansion coefficients. NASA-TN-D 5926.

4. James, M.R. and Cohen, J.B. "Study of the Precision of X-ray Stress Analysis," Adv. in X-ray Analysis 20, 1977 pp. 291-308.

5. Dull, D.L. and Amateau, M.F., Transverse Strength Properties of Graphite-Aluminum Composites, Final Report for Period 1, Oct. 1976 - Sept. 30, 1977; prepared for Naval Surface Weapons Center.

6. Marcus, H.L., Dull, D.L. and Amateau, M.F., "Scanning Auger Analysis of Fracture Surfaces in Graphite-Aluminum Composites," in Failure Modes in Composites IV, J.A. Cornie and F.W. Crossman, eds. Conference Proceedings, The Metallurgical Society of AIME, Fall, 1977.

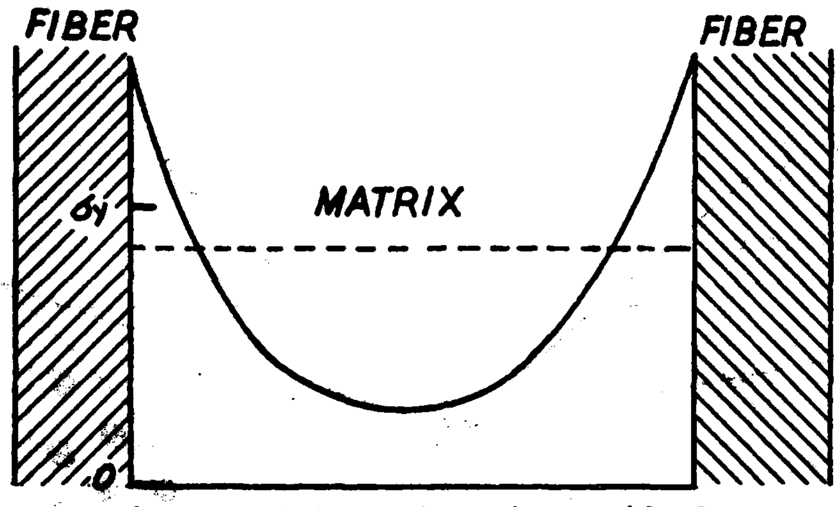

Figure 1. A simple model to show the residual stress distribution. The dotted line is an average value. The term σy is the yield strength of the matrix.

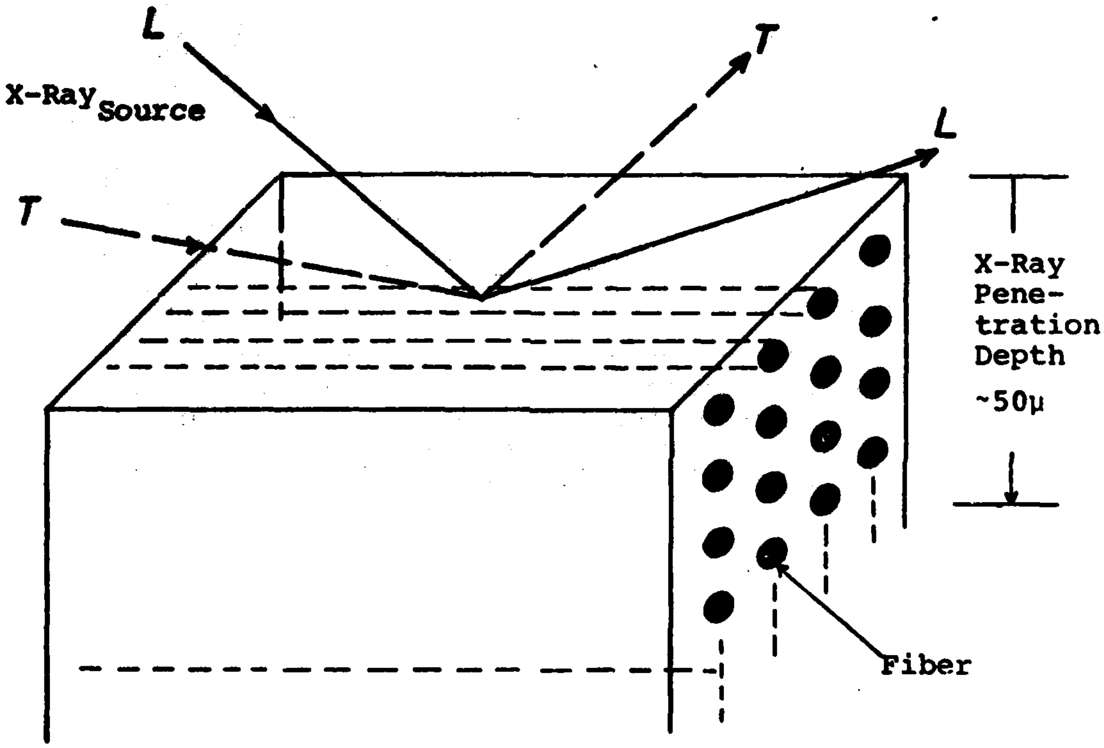

Figure 2. Measurement Geometry
L - Longitudinal
T - Transverse

Table 1

	Young's modulus 10^6 psi	Thermal expansion coefficient 10^{-6} / °C
Thornel 50 (Fiber in G3394)	60	-0.1~-0.4 (axial direction) to about 300°C
		~25 (transverse direction)
(Matrix Al-201)	10.2	23.22
Thornel 300 (Fiber in G3437)	35	~-0.23 (axial direction)
(Matrix Al-201)	10.2	23.22
Celion 6000 (Fiber in G3675)	34	~-0.23 (axial direction)
(Matrix Al-6061)	10.0	23.58

Table 2

Material	Transverse Strength MPa	Longitudinal Strength	Direction of Measurement Residual Stress	Diffraction Peak	Residual Stress MPa		Statistical Error MPa	Correlation Coefficient
G 3437	10	1120	L	420	199.38	±	3.87	0.9640
			T	420	166.28	±	3.61	0.9658
G 3394	20	763	L	420	228.38	±	1.46	0.9945
G 3675 [Away from the graphite-aluminum interface]	75	259	L	420	40.71	±	0.86	0.9507
			T	420	33.26	±	0.79	0.9788
G 3437 [cooled to liq. N_2 temp and measured at room temperature]	10 (before quench)	1120	L	420	144.11	±	2.55	0.9856
			T	420	120.20	±	2.25	0.9924

L = Longitudinal direction

T = Transverse direction

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